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[0001] **A BASE STATION FOR USE IN A CDMA COMMUNICATION SYSTEM USING AN ANTENNA ARRAY**

Sub A1

[0002] This application is a continuation application of U.S. Patent Application No. 09/602,963, filed June 23, 2000.

[0003] **BACKGROUND OF THE INVENTION**

[0004] **Field of the Invention**

[0005] The present invention relates generally to signal transmission and reception in a wireless code division multiple access (CDMA) communication system. More specifically, the invention relates to a system and method of transmission using an antenna array to improve signal reception in a wireless CDMA communication system.

[0006] **Description of the Prior Art**

[0007] A prior art CDMA communication system is shown in **Figure 1**. The communication system has a plurality of base stations **20-32**. Each base station **20** communicates using spread spectrum CDMA with user equipment (UEs) **34-38** within its operating area. Communications from the base station **20** to each UE **34-38** are referred to

as downlink communications and communications from each UE **34-38** to the base station **20** are referred to as uplink communications.

[0008] Shown in **Figure 2** is a simplified CDMA transmitter and receiver. A data signal having a given bandwidth is mixed by a mixer **40** with a pseudo random chip code sequence producing a digital spread spectrum signal for transmission by an antenna **42**. Upon reception at an antenna **44**, the data is reproduced after correlation at a mixer **46** with the same pseudo random chip code sequence used to transmit the data. By using different pseudo random chip code sequences, many data signals use the same channel bandwidth. In particular, a base station **20** will communicate signals to multiple UEs **34-38** over the same bandwidth.

[0009] For timing synchronization with a receiver, an unmodulated pilot signal is used. The pilot signal allows respective receivers to synchronize with a given transmitter allowing despreading of a data signal at the receiver. In a typical CDMA system, each base station **20** sends a unique pilot signal received by all UEs **34-38** within communicating range to synchronize forward link transmissions. Conversely, in some CDMA systems, for example in the B-CDMA™ air interface, each UE **34-38** transmits a unique assigned pilot signal to synchronize reverse link transmissions.

[00010] When a UE **34-36** or a base station **20-32** is receiving a specific signal, all

the other signals within the same bandwidth are noise-like in relation to the specific signal. Increasing the power level of one signal degrades all other signals within the same bandwidth. However, reducing the power level too far results in an undesirable received signal quality. One indicator used to measure the received signal quality is the signal to noise ratio (SNR). At the receiver, the magnitude of the desired received signal is compared to the magnitude of the received noise. The data within a transmitted signal received with a high SNR is readily recovered at the receiver. A low SNR leads to loss of data.

[00011] To maintain a desired signal to noise ratio at the minimum transmission power level, most CDMA systems utilize some form of adaptive power control. By minimizing the transmission power, the noise between signals within the same bandwidth is reduced. Accordingly, the maximum number of signals received at the desired signal to noise ratio within the same bandwidth is increased.

[00012] Although adaptive power control reduces interference between signals in the same bandwidth, interference still exists limiting the capacity of the system. One technique for increasing the number of signals using the same radio frequency (RF) spectrum is to use sectorization. In sectorization, a base station uses directional antennas to divide the base station's operating area into a number of sectors. As a result, interference between signals in differing sectors is reduced. However, signals within the same bandwidth within the same sector interfere with one another. Additionally, sectorized base stations commonly

assign different frequencies to adjoining sectors decreasing the spectral efficiency for a given frequency bandwidth. Accordingly, there exists a need for a system which further improves the signal quality of received signals without increasing transmitter power levels.

[00013] SUMMARY OF THE INVENTION

[00014] A base station has a plurality of transmitting antennas. From each transmitting antenna, a reference signal having a code uniquely associated with that antenna is transmitted. A data signal is transmitted such that different spread spectrum versions of the data signal are transmitted from each antenna. Each version has a different code for the respective transmitting antenna.

[00015] BRIEF DESCRIPTION OF THE DRAWINGS

[00016] **Figure 1** is a prior art wireless spread spectrum CDMA communication system.

[00017] **Figure 2** is a prior art spread spectrum CDMA transmitter and receiver.

[00018] **Figure 3** is the transmitter of the invention.

[00019] **Figure 4** is the transmitter of the invention transmitting multiple data signals.

[00020] **Figure 5** is the pilot signal receiving circuit of the invention.

[00021] **Figure 6** is the data signal receiving circuit of the invention.

[00022] **Figure 7** is an embodiment of the pilot signal receiving circuit.

[00023] **Figure 8** is a least mean squarred weighting circuit.

[00024] **Figure 9** is the data signal receiving circuit used with the pilot signal receiving circuit of **Figure 7**.

[00025] **Figure 10** is an embodiment of the pilot signal receiving circuit where the output of each RAKE is weighted.

[00026] **Figure 11** is the data signal receiving circuit used with the pilot signal receiving circuit of **Figure 10**.

[00027] **Figure 12** is an embodiment of the pilot signal receiving circuit where the antennas of the transmitting array are closely spaced.

[00028] **Figure 13** is the data signal receiving circuit used with the pilot signal receiving circuit of **Figure 12**.

[00029] **Figure 14** is an illustration of beam steering in a CDMA communication system.

[00030] **Figure 15** is a beam steering transmitter.

[00031] **Figure 16** is a beam steering transmitter transmitting multiple data signals.

[00032] **Figure 17** is the data receiving circuit used with the transmitter of **Figure 14**.

[00033] **Figure 18** is a pilot signal receiving circuit used when uplink and downlink signals use the same frequency.

[00034] **Figure 19** is a transmitting circuit used with the pilot signal receiving circuit of **Figure 18**.

[00035] **Figure 20** is a data signal receiving circuit used with the pilot signal receiving circuit of **Figure 18**.

[00036] **DESCRIPTION OF THE PREFERRED EMBODIMENTS**

[00037] The preferred embodiments will be described with reference to the drawing figures where like numerals represent like elements throughout. **Figure 3** is a transmitter of the invention. The transmitter has an array of antennas **48-52**, preferably 3 or 4 antennas. For use in distinguishing each antenna **48-52**, a different signal is associated with each antenna **56-60**. The preferred signal to associate with each antenna is a pilot signal as shown in **Figure 3**. Each spread pilot signal is generated by a pilot signal generator **56-60** using a different pseudo random chip code sequence and is combined by combiners **62-66** with the respective spread data signal. Each spread data signal is generated using data signal generator **54** by mixing at mixers **378-382** the generated data signal with a different pseudo random chip code sequence per antenna **48-52**, $\mathbf{D_1}$-$\mathbf{D_N}$. The combined signals are modulated to a desired carrier frequency and radiated through the antennas **48-52** of the array.

[00038] By using an antenna array, the transmitter utilizes spacial diversity. If spaced far enough apart, the signals radiated by each antenna **48-52** will experience different multipath distortion while traveling to a given receiver. Since each signal sent by an antenna **48-52** will follow multiple paths to a given receiver, each received signal will have many multipath components. These components create a virtual communication channel between each antenna **48-52** of the transmitter and the receiver. Effectively, when signals transmitted by one antenna **48-52** over a virtual channel to a given receiver are fading, signals from the other antennas **48-52** are used to maintain a high received SNR. This effect is achieved by the adaptive combining of the transmitted signals at the receiver.

[00039] **Figure 4** shows the transmitter as used in a base station **20** to send multiple data signals. Each spread data signal is generated by mixing at mixers **360-376** a corresponding data signal from generators **74-78** with differing pseudo random chip code sequences $\mathbf{D_{11}}$-$\mathbf{D_{NM}}$. Accordingly, each data signal is spread using a different pseudo random chip code sequence per antenna **48-52**, totaling N x M code sequences. N is the number of antennas and M is the number of data signals. Subsequently, each spread data signal is combined with the spread pilot signal associated with the antenna **48-52**. The combined signals are modulated and radiated by the antennas **48-52** of the array.

[00040] The pilot signal receiving circuit is shown in **Figure 5**. Each of the

transmitted pilot signals is received by the antenna **80**. For each pilot signal, a despreading device, such as a RAKE **82-86** as shown in the **Figure 5** or a vector correlator, is used to despread each pilot signal using a replica of the corresponding pilot signal's pseudo random chip code sequence. The despreading device also compensates for multipath in the communication channel. Each of the recovered pilot signals is weighted by a weighting device **88-92**. Weight refers to both magnitude and phase of the signal. Although the weighting is shown as being coupled to a RAKE, the weighting device preferably also weights each finger of the RAKE. After weighting, all of the weighted recovered pilot signals are combined in a combiner **94**. Using an error signal generator **98**, an estimate of the pilot signal provided by the weighted combination is used to create an error signal. Based on the error signal, the weights of each weighting device **88-92** are adjusted to minimize the error signal using an adaptive algorithm, such as least mean squared (LMS) or recursive least squares (RLS). As a result, the signal quality of the combined signal is maximized.

[00041] **Figure 6** depicts a data signal receiving circuit using the weights determined by the pilot signal recovery circuit. The transmitted data signal is recovered by the antenna **80**. For each antenna **48-52** of the transmitting array, the weights from a corresponding despreading device, shown as a RAKE **82-86**, are used to filter the data signal using a replica of the data signal's spreading code used for the corresponding transmitting antenna. Using the determined weights for each antenna's pilot signal, each weighting device

106-110 weights the RAKE's despread signal with the weight associated with the corresponding pilot. For instance, the weighting device **88** corresponds to the transmitting antenna **48** for pilot signal 1. The weight determined by the pilot RAKE **82** for pilot signal 1 is also applied at the weighting device **106** of **Figure 6**. Additionally, if the weights of the RAKE's fingers were adjusted for the corresponding pilots signal's RAKE **82-86**, the same weights will be applied to the fingers of the data signal's RAKE **100-104**. After weighting, the weighted signals are combined by the combiner **112** to recover the original data signal.

[00042] By using the same weights for the data signal as used with each antenna's pilot signal, each RAKE **82-86** compensates for the channel distortion experienced by each antenna's signals. As a result, the data signal receiving circuit optimizes the data signals reception over each virtual channel. By optimally combining each virtual channel's optimized signal, the received data signal's signal quality is increased.

[00043] **Figure 7** shows an embodiment of the pilot signal recovery circuit. Each of the transmitted pilots are recovered by the receiver's antenna **80**. To despread each of the pilots, each RAKE **82-86** utilizes a replica of the corresponding pilot's pseudo random chip code sequence, P_1-P_N. Delayed versions of each pilot signal are produced by delay devices **114-124**. Each delayed version is mixed by a mixer **126-142** with the received signal. The mixed signals pass through sum and dump circuits **424-440** and are weighted using mixers **144-160** by an amount determined by the weight adjustment device **170**. The weighted

multipath components for each pilot are combined by a combiner **162-164**. Each pilot's combined output is combined by a combiner **94**. Since a pilot signal has no data, the combined pilot signal should have a value of 1+j0. The combined pilot signal is compared to the ideal value, 1+j0, at a subtractor **168**. Based on the deviation of the combined pilot signal from the ideal, the weight of the weighting devices **144-160** are adjusted using an adaptive algorithm by the weight adjustment device **170**.

[00044] A LMS algorithm used for generating a weight is shown in **Figure 8**. The output of the subtractor **168** is multiplied using a mixer **172** with the corresponding despread delayed version of the pilot. The multiplied result is amplified by an amplifier **174** and integrated by an integrator **176**. The integrated result is used to weight, W_{1M}, the RAKE finger.

[00045] The data receiving circuit used with the embodiment of **Figure 7** is show for a base station receiver in **Figure 9**. The received signal is sent to a set of RAKEs **100-104** respectively associated with each antenna **48-52** of the array. Each RAKE **100-104**, produces delayed versions of the received signal using delay devices **178-188**. The delayed versions are weighted using mixers **190-206** based on the weights determined for the corresponding antenna's pilot signal. The weighted data signals for a given RAKE **100-104** are combined by a combiner **208-212**. One combiner **208-212** is associated with each of the N transmitting antennas **48-52**. Each combined signal is despread M times by mixing at a

mixer **214-230** the combined signal with a replica of the spreading codes used for producing the M spread data signals at the transmitter, D_{11}-D_{NM}. Each despread data signal passes through a sum and dump circuit **232-248**. For each data signal, the results of the corresponding sum and dump circuits are combined by a combiner **250-254** to recover each data signal.

[00046] Another pilot signal receiving circuit is shown in **Figure 10**. The despreading circuits **82-86** of this receiving circuit are the same as **Figure 7**. The output of each RAKE **82-86** is weighted using a mixer **256-260** prior to combining the despread pilot signals. After combining, the combined pilot signal is compared to the ideal value and the result of the comparison is used to adjust the weight of each RAKE's output using an adaptive algorithm. To adjust the weights within each RAKE **82-86**, the output of each RAKE **82-86** is compared to the ideal value using a subtractor **262-266**. Based on the result of the comparison, the weight of each weighting device **144-160** is determined by the weight adjustment devices **268-272**.

[00047] The data signal receiving circuit used with the embodiment of **Figure 10** is shown in **Figure 11**. This circuit is similar to the data signal receiving circuit of **Figure 9** with the addition of mixers **274-290** for weighting the output of each sum and dump circuit **232-248**. The output of each sum and dump circuit **232-248** is weighted by the same amount as the corresponding pilot's RAKE **82-86** was weighted. Alternatively, the output of each

RAKE's combiner **208-212** may be weighted prior to mixing by the mixers **214-230** by the amount of the corresponding pilot's RAKE **82-86** in lieu of weighting after mixing.

[00048] If the spacing of the antennas **48-52** in the transmitting array is small, each antenna's signals will experience a similar multipath environment. In such cases, the pilot receiving circuit of **Figure 12** may be utilized. The weights for a selected one of the pilot signals are determined in the same manner as in **Figure 10**. However, since each pilot travels through the same virtual channel, to simplify the circuit, the same weights are used for despreading the other pilot signals. Delay devices **292-294** produce delayed versions of the received signal. Each delayed version is weighted by a mixer **296-300** by the same weight as the corresponding delayed version of the selected pilot signal was weighted. The outputs of the weighting devices are combined by a combiner **302**. The combined signal is despread using replicas of the pilot signals' pseudo random chip code sequences, P_2-P_n, by the mixers **304-306**. The output of each pilot's mixer **304-306** is passed through a sum and dump circuit **308-310**. In the same manner as **Figure 10**, each despread pilot is weighted and combined.

[00049] The data signal recovery circuit used with the embodiment of **Figure 12** is shown in **Figure 13**. Delay devices **178-180** produce delayed versions of the received signal. Each delayed version is weighted using a mixer **190-194** by the same weight as used by the

pilot signals in **Figure 12**. The outputs of the mixers are combined by a combiner **208**. The output of the combiner **208** is inputted to each data signal despreader of **Figure 13**.

[00050] The invention also provides a technique for adaptive beam steering as illustrated in **Figure 14**. Each signal sent by the antenna array will constructively and destructively interfere in a pattern based on the weights provided each antenna **48-52** of the array. As a result, by selecting the appropriate weights, the beam **312-316** of the antenna array is directed in a desired direction.

[00051] **Figure 15** shows the beam steering transmitting circuit. The circuit is similar to the circuit of **Figure 3** with the addition of weighting devices **318-322**. A target receiver will receive the pilot signals transmitted by the array. Using the pilot signal receiving circuit of **Figure 5**, the target receiver determines the weights for adjusting the output of each pilot's RAKE. These weights are also sent to the transmitter, such as by using a signaling channel. These weights are applied to the spread data signal as shown in **Figure 15**. For each antenna, the spread data signal is given a weight by the weighting devices **318-322** corresponding to the weight used for adjusting the antenna's pilot signal at the target receiver providing spatial gain. As a result, the radiated data signal will be focused towards the target receiver. **Figure 16** shows the beam steering transmitter as used in a base station sending multiple data signals to differing target receivers. The weights received by the target receiver are applied to the corresponding data signals by weighting devices **324-340**.

[00052] **Figure 17** depicts the data signal receiving circuit for the beam steering transmitter of **Figures 15** and **16**. Since the transmitted signal has already been weighted, the data signal receiving circuit does not require the weighting devices **106-110** of **Figure 6**.

[00053] The advantage of the invention's beam steering are two-fold. The transmitted data signal is focused toward the target receiver improving the signal quality of the received signal. Conversely, the signal is focused away from other receivers reducing interference to their signals. Due to both of these factors, the capacity of a system using the invention's beam steering is increased. Additionally, due to the adaptive algorithm used by the pilot signal receiving circuitry, the weights are dynamically adjusted. By adjusting the weights, a data signal's beam will dynamically respond to a moving receiver or transmitter as well as to changes in the multipath environment.

[00054] In a system using the same frequency for downlink and uplink signals, such as time division duplex (TDD), an alternate embodiment is used. Due to reciprocity, downlink signals experience the same multipath environment as uplink signals send over the same frequency. To take advantage of reciprocity, the weights determined by the base station's receiver are applied to the base station's transmitter. In such a system, the base station's receiving circuit of **Figure 18** is co-located, such as within a base station, with the transmitting circuit of **Figure 19**.

[00055] In the receiving circuit of **Figure 18**, each antenna **48-52** receives a respective pilot signal sent by the UE. Each pilot is filtered by a RAKE **406-410** and weighted by a weighting device **412-416**. The weighted and filtered pilot signals are combined by a combiner **418**. Using the error signal generator **420** and the weight adjustment device **422**, the weights associated with the weighting devices **412-416** are adjusted using an adaptive algorithm.

[00056] The transmitting circuit of **Figure 19** has a data signal generator **342** to generate a data signal. The data signal is spread using mixer **384**. The spread data signal is weighted by weighting devices **344-348** as were determined by the receiving circuit of **Figure 19** for each virtual channel.

[00057] The circuit of **Figure 20** is used as a data signal receiving circuit at the base station. The transmitted data signal is received by the multiple antennas **48-52**. A data RAKE **392-396** is coupled to each antenna **48-52** to filter the data signal. The filtered data signals are weighted by weighting devices **398-402** by the weights determined for the corresponding antenna's received pilot and are combined at combiner **404** to recover the data signal. Since the transmitter circuit of **Figure 19** transmits the data signal with the optimum weights, the recovered data signal at the UE will have a higher signal quality than provided by the prior art.

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